Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Amendment of the Commission's Rules to Promote Aviation Safety	)	WT Docket No. 19-140
	)	
WiMAX Forum Petition to Adopt Service Rules for the Aeronautical Mobile Airport Communications System (AeroMACS)	)	RM-11793
	)	
Petition of Sierra Nevada Corporation for Amendment of the Commission's Rules to Allow for Enhanced Flight Vision System Radar under Part 87	)	RM-11799
	)	
Petition of Aviation Spectrum Resources, Inc. for Amendment of Sections 87.173(b) and 87.263(a) of the FCC's Rules to Allow Use of the Lower 136 MHz Band by Aeronautical Enroute Stations	)	RM-11818
	)	
Petition of Airports Council International-North America Regarding Aeronautical Utility Mobile Stations	)	RM-11832

REPLY COMMENTS OF SIERRA NEVADA CORPORATION

Sierra Nevada Corporation ("SNC") submits these reply comments in response to comments filed in the above-captioned Notice of Proposed Rulemaking ("NPRM"), which proposes numerous changes to the Federal Communications Commission's ("FCC" or "Commission") rules for the Part 87 Aviation Radio Service.[1/] SNC supports the Commission's

[1/] *Amendment of the Commission's Rules to Promote Aviation Safety; WiMAX Forum Petition to Adopt Service Rules for the Aeronautical Mobile Airport Communications System (AeroMACS); Petition of Sierra Nevada Corporation for Amendment of the Commission's Rules to Allow for Enhanced Flight Vision System Radar under Part 87; Petition of Aviation Spectrum Resources, Inc. for Amendment of Sections 87.173(b) and 87.263(a) of the FCC's Rules to Allow Use of the Lower 136 MHz Band by Aeronautical Enroute Stations; Petition of Airports Council International-North America Regarding Aeronautical Utility Mobile Stations*, Notice of Proposed Rulemaking, FCC 19-53 (rel. June 7, 2019) ("NPRM").

proposals relating to the establishment of rules for 90 GHz Enhanced Flight Vision Systems ("EFVS") radar. Adopting these proposed rules is in the public interest and will result in satisfying Federal Aviation Administration ("FAA") NextGen requirements, encouraging the development of a new commercial product, facilitating technology transfer from military to civilian use, and promoting U.S. competitiveness internationally by enabling the development of EFVS.

I. THE RECORD SUPPORTS ADOPTION OF THE COMMISSION'S PROPOSED RULES ENABLING 90 GHz ENHANCED FLIGHT VISION SYSTEMS RADAR

The record in this proceeding strongly supports adoption of the Commission's proposed rules enabling the operation of 90 GHz EFVS radar.

a) EFVS Radar is in The Public Interest

Supporting the Commission's tentative conclusion, SNC explained in its comments how allowing the use of EFVS radar would serve the public interest, including by enhancing a pilot's natural vision and enabling landings in moderate to severe Degraded Visual Environments ("DVE").[2/] The Air Line Pilots Association, Int'l ("ALPA"); Aviation Spectrum Resources, Inc. ("ASRI"); the Boeing Company ("Boeing"); and Collins Aerospace ("Collins") all voice their support for the proposal and agree that its adoption would benefit the public.[3/] Even the National Academy of Sciences' Committee on Radio Frequencies ("CORF"), which opposes granting EFVS radar primary status in the 90 GHz band, acknowledges the benefits of EFVS radar.[4/]

2/ Comments of Sierra Nevada Corporation, WT Docket No. 19-140, at 2 (filed Sept. 3, 2019) ("SNC Comments").

3/ Comments of ALPA, WT Docket No. 19-140, at 1 (filed Sept. 3, 2019) ("ALPA Comments"); Comments of ASRI, WT Docket No. 19-140, at 13 (filed Sept. 3, 2019) ("ASRI Comments"); Comments of the Boeing Company, WT Docket No. 19-140, at 3 (filed Sept. 3, 2019) ("Boeing Comments"); Comments of Collins Aerospace, WT Docket No. 19-140, at 5 (filed Sept. 3, 2019) ("Collins Comments").

4/ Comments of CORF, WT Docket No. 19-140, at 14 (filed Aug. 12, 2019) ("CORF Comments").

ALPA explains that allowing the requested EFVS operations is in the public interest and has the potential to greatly enhance aviation safety by enabling pilots to have an additional visual-like reference to surrounding terrain, obstacles, buildings, and the airport environment, which greatly enhances the safety of approaches, landings, and similar procedures.[5/] ASRI supports the introduction of EFVS radar in the 92-95.5 GHz frequency range and acknowledges its usefulness "as both a navigational tool and additional means of aviation safety in low visibility conditions."[6/] Boeing also agrees that EFVS "will foster measurable benefits for aviation safety and efficiency"[7/] including by "enhanc[ing] safety and reduc[ing] flight delays and cancellations, fuel consumption and emissions, aircraft operational costs, and passenger travel time."[8/] Finally, Collins, which manufactures EFVS systems, emphasized that these systems increase "flexibility for pilots to land in more locations with increased frequency, including when weather and visibility conditions are poor" or would otherwise close airports.[9/]

Collins disagrees, however, with the statement that "millimeter wave radar is superior to existing technology using infrared camera sensors."[10/] Collins also claims that the development of future radar-based EFVS systems might require the Commission to explore alternative frequency bands.[11/] In SNC's view, 90 GHz radar is the optimal compromise of radar antenna size, resolution obtained, radar atmospheric losses, DVE obscurant penetration, and radar component cost and availability. 90 GHz radar delivers sufficiently deep penetration through obscurants – far more so than infrared systems – while also providing sufficient resolution for

5/ ALPA Comments at 2.
6/ ASRI Comments at 13.
7/ Boeing Comments at 3.
8/ *Id.*; *see also* NPRM ¶ 11.
9/ Collins Comments at 5-6.
10/ NPRM ¶ 11; Collins Comments at 6.
11/ Collins Comments at 6-7.

viewing. Radar operating at lower frequencies, while also providing deep penetration through obscurants, require larger antennas than 90 GHz radar antennas to resolve at a similar resolution; for example, one operating at 35 GHz would be approximately three times larger than one developed for 90 GHz for the same resolution performance. These factors all lead to the conclusion that 90 GHz radar for EFVS is extremely beneficial and in public interest.

The Commission need not resolve the question of what technology is optimal before it adopts the proposed rules. There are clear benefits to justify the rules, and the Commission can allow the market to decide whether 90 GHz radar or other frequencies (or technologies) are preferable. Further, the use of other frequency bands for EFVS radar is not before the Commission in this proceeding; instead, the Commission should evaluate the proposal on its merits, which will lead to the conclusion that it should be adopted as in the public interest.

b) The FCC Should Adopt its Proposed Definition of EFVS

A few parties have questioned the Commission's proposed definition of EFVS, which adopts the FAA's definition.[12/] AiRXOS, Inc. ("AiRXOS") asks the Commission to clarify that the Part 87 definition of EFVS includes, for UAS, on-aircraft controls and on-ground displays.[13/] As AiRXOS acknowledges, the NPRM did "not directly seek comment on how its proposed rules might affect the UAS industry."[14/] While SNC takes no position on the value of such a clarification in the future, this question presently is not ripe for consideration, and the Commission should use the FAA's definition of EFVS for purposes of this proceeding.

12/ NPRM ¶ 13 n.24.

13/ Comments of AiRXOS, WT Docket No. 19-140, at 2 (filed Sept. 3, 2019) ("AiRXOS Comments"); Comments of AIRBUS, WT Docket No. 19-140, at 3 (filed Sept. 3, 2019) ("AIRBUS Comments").

14/ AiRXOS Comments at 4.

c) The FAA Determines Operational Rules for EFVS

Some commenters contend that the Commission should define the operating conditions for EFVS radar.[15/] For example, AIRBUS states that it is possible that EFVS radar may be used above the "low altitude" at which SNC explains the system will be used.[16/] In addition, CORF suggests that the FCC issue Part 87 regulations to define the conditions under which EFVS may operate.[17/] These are not issues for the Commission. When Radionavigation use is requested under Part 87, the Commission does not set the technical parameters for these operations, but instead looks exclusively at a particular proposed operation during the certification process. The Commission's role with regard to EFVS radar is to allocate frequencies for use, not to determine the operating conditions under which it will be used, which is the FAA's role as the relevant aviation safety agency.

II. SUCCESSFUL CO-EXISTENCE BETWEEN 90 GHz EFVS RADAR AND OTHER USERS IS POSSIBLE

In the NPRM, the Commission sought comment on the ability of EFVS radar to co-exist successfully with other users in the 92-95.5 GHz band.[18/] Several parties filed comments addressing this issue, in particular with regard to the operations of Foreign Object Debris detection systems ("FODs"), which are radar systems that may be deployed near airport runways, and radio astronomy ("RAS"). SNC is committed to ensuring coexistence with other users. Other parties agree that EFVS is compatible with other existing or potential users and, as demonstrated below and in the attached Technical Statement, EFVS radar may be deployed without concern about harmful interference to others.

15/ AIRBUS Comments at 4.

16/ *Id*.

17/ CORF Comments at 10-11.

18/ NPRM ¶12.

a) Spectrum Sharing with Foreign Object Debris Systems can be Accomplished through Channel Selection

Some commenters expressed concern about the coexistence between EFVS and FODs if both systems operate in the same location and frequency.[19/] As SNC explained in its comments, it anticipates that EFVS radar will be compatible with FODs, and it supports the research engaged in by the WRC-19 Working Party 5G to consider FODs in the 92-100 GHz band.[20/]

The record demonstrates that coexistence between EFVS and FODs is possible. Several factors combine to make the probability of an EFVS system causing harmful interference to FODs extremely unlikely.[21/] First and foremost, the operational characteristics of EFVS radar make interference unlikely: EFVS will use low power, operate at low altitude and with short duration, have a low duty cycle, and will operate only under adverse weather conditions.[22/] Second, coexistence through coordination can be arranged by FODs and EFVS operators. Representatives from SNC and Moog, Inc. ("Moog"), which has developed a FOD system, have discussed coexistence between EFVS and FOD systems operating in the 94 GHz band at the same airport.[23/] Both SNC and Moog agree that there is sufficient spectrum such that sharing is readily achievable via channel sharing. The two systems, even when operating at the same location and at maximum capacity, would use no more than about 60% of the band combined.[24/] Moog filed comments indicating that it does not object to the introduction of EFVS radar in the 90 GHz band given these discussions because it believes that the two systems can coexist.[25/]

19/ *See* Comments of Moog, Inc., WT Docket No. 19-140 (filed Sept. 3, 2019) ("Moog Comments").
20/ SNC Comments at 6.
21/ SNC Comments at 5.
22/ *Id*.
23/ Moog Comments at 4.
24/ *See Id*.
25/ Moog Comments at 1.

Several other commenters agree with this conclusion. ALPA believes that both systems can work together to enable coexistence, since both applications provide safety enhancements to airport operations.[26/] However, if co-existence proves infeasible, ALPA believes that EFVS operations should take precedence over FOD detection activities, a position with which SNC agrees.[27/] ASRI also agrees that both FOD systems and EFVS have benefits for aviation that should drive both proponents to find a way to coexist.[28/]

b) SNC's EFVS Radar will not Cause Harmful Interference to Radio Astronomy Observations

Just one party, CORF, is opposed to the Commission's proposal to allow Radionavigation as a primary allocation in the 90 GHz band, due to what it claims is "high potential for radio interference from airborne radar systems."[29/] As SNC demonstrates, there is an exceedingly limited likelihood that EFVS radars would cause harmful interference to radio astronomy operations. This is in large part due to geographic separation, as RAS is in use on these frequencies only in a limited number of generally remote locations in the United States. SNC has attached a Technical Statement demonstrating that its operations will meet ITU requirements for protecting RAS.[30/] Other concerns raised by CORF may be addressed through either the equipment approval processes or FAA regulations.

At the outset, SNC notes that Radionavigation already is allowed on a primary basis in the upper portion of the frequency range, 95-95.5 GHz, which is part of the 95-100 GHz band.[31/] Therefore, as the Commission correctly explains, its decision with regard to this frequency is

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26/ ALPA Comments at 2.
27/ *Id*.
28/ ASRI Comments at 13.
29/ CORF Comments at 2.
30/ SNC Technical Statement, attached herein as Appendix A.
31/ 47 C.F.R. § 2.106.

only whether to allow Part 87 in the band, not Radionavigation generally.[32/] Further, US 161 does not apply to 95-100 GHz, which means that while steps must be taken to protect RAS in accordance with US 342, there is no absolute protection afforded RAS in this frequency range.[33/]

With regard to 92-95 GHz, the band presently is allocated for multiple users on a primary basis: Fixed, Mobile, Radio Astronomy, and Radiolocation (radar) through most of the band, with 94-94.1 GHz allocated to Earth Exploration Satellite ("EESS"), Radiolocation, and Space Research on a primary basis, and radio astronomy on a secondary basis.[34/] Radar systems have been allowed to operate in the band on a primary basis since the Commission granted primary status to RAS and established the rules for fixed services in the band.[35/] As NTIA noted at the time of that rulemaking proceeding, the 90 GHz band differed from the 70 and 80 GHz bands because radar was already allowed on a primary basis.[36/] Additionally, NTIA explained that "[t]here are also military airborne applications for radar in this band."[37/] Since RAS and military airborne radar have co-existed for decades in the band, the entry of civilian airborne radar is not novel. The only question is how to assure successful co-existence with a different type of airborne radar.

CORF suggests that the ITU-R RA.769 emission limits should apply to ensure protection of radio astronomy observatories. SNC agrees that RA.769 is the correct standard, and SNC's Technical Statement contains an interference analysis that demonstrates the impact of EFVS radar operating near radio astronomy observatories using this standard. In that statement, SNC

32/ NPRM ¶ 13.

33/ *Id*.

34/ 47 C.F.R. § 2.106.

35/ *Allocation and Service Rules for the 71-76 GHz, 81-86 GHz and 92-95 GHz Bands,* Notice of Proposed Rulemaking, 17 FCC Rcd. 12182 (2002) ("70/80/90 GHz NPRM").

36/ Reply Comments of the National Telecommunications and Information Administration, WT Docket 02-146, at 10 (filed Feb. 3, 2003) ("NTIA Reply").

37/ *Id*.

demonstrates that SNC radar system will meet the ITU Recommendations set out in ITU-R RA.1513-2 for evaluating allowable loss to any RAS observation in frequency bands where RAS is a primary service.[38/]

CORF suggests limiting the use of airborne radars within the coordination zones to periods when the atmospheric opacity is greater than 1.2 dB/km.[39/] This is an unnecessary condition. First, as noted above, US 161 does not apply to 95-95.5 GHz. Second, SNC's Technical Statement demonstrates that RAS observations will be protected adequately without this limitation. And third, the SNC system uses navigation position and database information regarding terrain, which means it has the capacity to recognize observatory locations and adjust operations if needed to provide additional protection to a particular RAS site.

CORF expresses concern about possible interference to RAS observations on other frequencies, due to harmonics, spurious emissions, or out-of-band emissions.[40/] The technical performance of any particular EFVS radar will be considered during the equipment approval processes, in which both the FCC and the FAA are engaged. In the case of SNC's radar, these are designed for federal military customers as well as for commercial users, and therefore meet military quality standards for electromagnetic interference ("EMI") and electromagnetic compatibility ("EMC"). Military standards are generally more stringent than commercial standards in terms of managing interference and electromagnetic compatibility, including harmonics and out-of-band emissions ("OOBE"). In addition, technical means exist to reduce out-of-band emissions to acceptable levels. For these reasons, SNC does not anticipate that any

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38/ SNC Technical Statement. One notable difference between the calculations used by CORF and the SNC analysis is that CORF assumes that the SNC radar operates with a 3 GHz bandwidth (*see* CORF Comments at n.6) while the bandwidth is between 30 to 400 MHz, depending on operations.

39/ CORF Comments at 10.

40/ CORF Comments at 11-12.

harmful interference will occur from harmonics, spurious emissions, or out-of-band emissions from its EFVS radar.

Finally, CORF suggests that new users of any band in which RAS has primary status should not be allowed without a compatibility study.[41/] This is not in line with Commission practice, as the agency does not require a full compatibility analyses as a matter of course prior to opening spectrum to new users, but rather makes decisions on a case-by-case basis looking at factors relevant to a particular frequency band. New technology should not be delayed under the guise of requiring a compatibility analysis when other methods, such as the Technical Statement attached here, can be used to determine good spectrum management.

III. CONCLUSION

As the record demonstrates, allowing 90 GHz EFVS radar under the proposed Part 87 rules is in the public interest. The Commission should act promptly on its proposal in the NPRM and adopt rules for EFVS radar operations.

Respectfully submitted,
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September 30, 2019

41/ CORF Comments at 10-11.

TECHNICAL STATEMENT

for the

Enhanced Flight Vision System (EFVS) Product Line DVE Radar Sensors

September 24, 2019

444 Salomon Circle
Sparks, Nevada 89434
MFG IDENT CODE 8X691

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1.0 INTRODUCTION

The purpose of this document is to provide a technical overview of Sierra Nevada Corporation (SNC) Degraded Visual Environment (DVE) Radar Sensors, and to provide an analysis of their interference characteristics with other users at or near their operating frequencies. These radar sensors will be operated as the primary sensor in military and commercial Enhanced Flight Vision Systems.

Both commercial and military aviation suffer when attempting to operate aircraft in degraded visual conditions. The US military has lost hundreds of lives and billions of dollars in aircraft and equipment over the past decade due to accidents from operation in DVE. In commercial aviation, approximately 10% of all accidents are weather-related, and billions of dollars are lost by commercial cargo carriers that must divert to alternate airports or cancel flights due to fog, smog, etc.

Previous generation Enhanced Flight Vision Systems, based on infrared camera sensors, have proven inadequate to combat these issues. Infrared cameras, operating at infrared wavelengths near the visual spectrum, suffer from the same physics constraints as a pilot's native vision—the infrared cameras cannot "see" through heavy degraded visual conditions.

SNC has invented a radar system specifically designed to aid pilots and greatly enhance aviation safety when operating in degraded visual conditions.

2.0 DVE RADAR SYSTEM OVERVIEW

SNC's Enhanced Flight Vision Systems (EFVS) operate as shown in Figure 1 below.

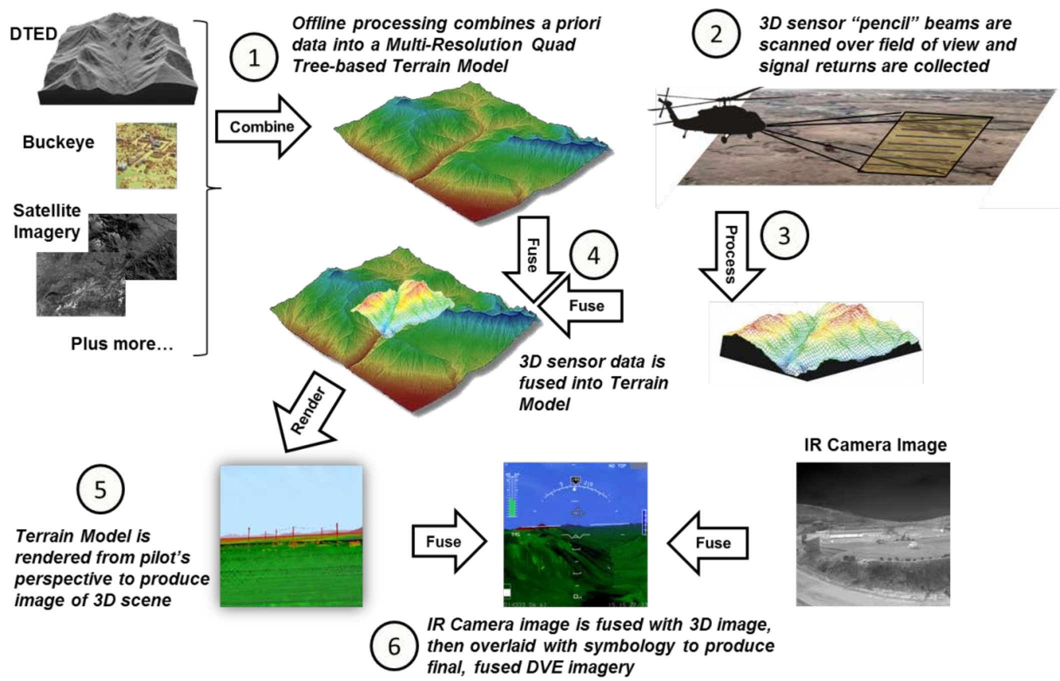

Figure 1. Enhanced Flight Vision System Operation

The EFVS combines real-time sensor inputs with *a priori* database information (digital terrain elevation data, satellite imagery, etc.) to produce real-time, "see through" imagery in degraded visual conditions. The SNC DVE Radar Sensor provides the functionality highlighted by item "2" in Figure 1, scanning a radar "pencil"-beam over the field of view in front of the aircraft and generating three-dimensional position information (range, azimuth, and elevation) of terrain and obstacles within that field of view. The radar sensor operates at wavelengths that penetrate most obscurants that cause degraded visual conditions and, thus, provide improved performance and enhanced safety over IR-only based Enhanced Flight Vision Systems.

SNC has designed and manufactured several prototype DVE Radar Sensors over the past decade. These sensors have been experimentally licensed through the Federal Communications Commission. SNC is seeking an FCC rule change to allow two versions of its DVE Radar Sensor product—the model number 0352 DVE Radar Sensor for fixed wing usage, and the model number 0452 DVE Radar Sensor for helicopter usage. The operating characteristics of these radar sensors are summarized in Table 1.

Table 1. DVE Radar Sensor Characteristics

Parameter	Value for 0352 Model Radar	Value for 0452 Model Radar
Operating Frequency Range	92.5 to 95.5 GHz	92.5 to 95.5 GHz
Maximum Instantaneous Bandwidth Used	100 MHz	400 MHz
Field of View (FOV)	28° az by 7° el	30° az by 30° el
Time to Scan FOV	600 msec	700 msec
Peak Transmit Power	3 W	3 W

The radar transmits and receives return signals from objects within the field of view. That, together with knowledge of the antenna position in azimuth and elevation at the time of reception, provides a three-dimensional position measurement of that object. The EFVS system processor computes the three-dimensional position of the objects detected within the radar's field of view and uses that information to formulate and display situational awareness for pilot situational awareness as was described in Figure 1.

3.0 INTERFERENCE ANALYSIS

3.1 Interference Protection Criteria - Radio Astronomy Service

ITU-R RA.769-2 establishes the IPC for radio astronomy. The NTIA Manual regulation footnotes for US161 and US342 lists VLBI observation and continuum observations, but not spectral line observations, within the 92.5-95.5 GHz bands. However, other sources[1] indicate that the band 93.07-93.27 GHz is used for spectral line observation of Diazenylium (N_2H+). Therefore, the criteria given in ITU-R RA.769-2 Tables 1, 2, and 3 are all applicable.

ITU-R RA.769-2 Table 1, for continuum observations, lists the threshold interference levels as -189 dBW, -129 dB(W/m^2), and -228 dB(W/(m^2 Hz)) at 89 GHz, the nearest specified frequency.

[1] NTIA Special Publication 98-35, "Radio Astronomy Spectrum Planning Options - Appendix C, Preferred Frequency Bands for Radio Astronomical Measurements", Table C-1, "Radio Frequency Lines of the Greatest Importance to Radio Astronomy at Frequencies Below 275 GHz", https://www.ntia.doc.gov/legacy/osmhome/reports/pub9835/Raspapnd.htm, accessed 26 Sept 2019.

Table 2, for spectral line observations, lists the threshold interference levels as -209 dBW, -148 dB(W/m2), and -208 dB(W/(m2 Hz)) at 88.6 GHz. Table 3, for VLBI observations, lists the threshold interference level as -172 dB(W/(m^2 Hz)) at 86 GHz. Rather than re-compute the interference levels within the 92.5 to 95.5 GHz band under consideration, we will adopt the more stringent values at these slightly lower frequencies.

Per ITU-R RA.1513-2, a criterion of 5% should be used for evaluating data loss to the radio astronomy service from interference in any frequency band in which radio astronomy is allocated on a primary basis.

Table 2 summarizes the IPC to be used for this analysis.

Table 2. Interference Protection Criteria Summary

Service	Interference Protection Criteria	% of Time
RADIO ASTRONOMY	Continuum: -189 dBW, -129 dB (W/m^2), and -228 dB (W/(m^2 Hz))	<5
	Spectral Line: -209 dBW, -148 dB (W/m^2), and -208 dB(W/(m^2 Hz))	<5
	VLBI: -172 dB(W/(m^2 Hz))	<5

3.2 Antenna Pattern Model

For the purposes of analysis, we are using a simplified model of the antenna gain as a function of off-boresight angle. This model is higher in gain than the measured envelope of the real azimuth and elevation antenna patterns of either sensor. The simplified model has a region from -3° to +3° around the antenna boresight that envelopes the main lobe and near-in sidelobes of the real radar antenna patterns. Outside this region, the modeled gain falls off at a lower rate, enveloping any further-out sidelobes of the real antenna patterns. The simplified antenna model is shown in Figure 2 below, with a measured antenna pattern from the Model 0452 sensor superimposed for reference.

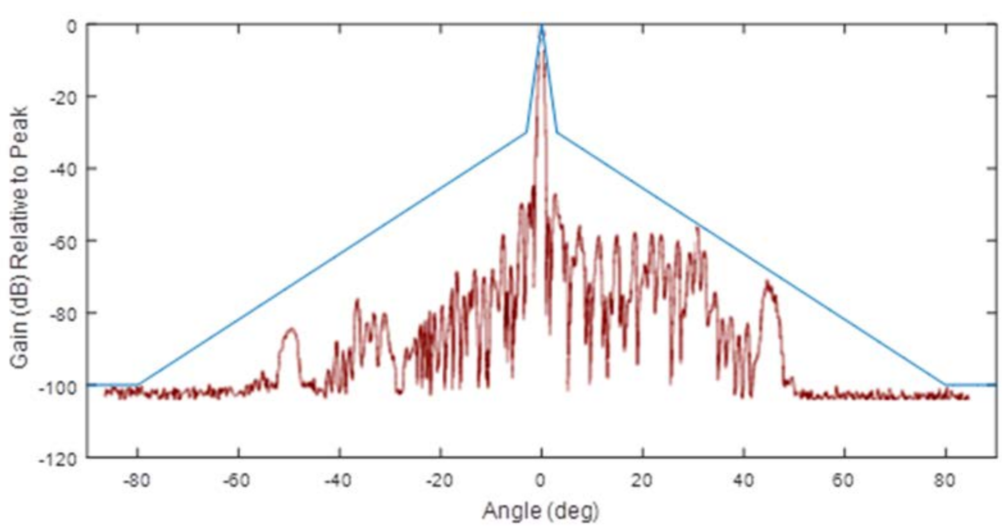

Figure 2. Simplified Antenna Pattern for Analysis

3.3 Analysis

There are approximately 36 radio astronomy observation sites operating worldwide within the bandwidth occupied by the SNC EFVS radar sensors. These radio telescopes and their locations are given in Table 3 below.

Table 3. List of Radio Telescope Sites Operating in 92.5-95.5 GHz Band

Name	Location	Frequency Range	Remarks
Australia Telescope Compact Array (ATCA)	Narrabri, New South Wales S 30 18 46.6 E 149 33 30.5	1.1-105 GHz	6x22m dish aperture synthesis array, operated by CSIRO as part of the ATNF (Australia Telescope National Facility).
Mopra Radio Telescope	Coonabarabran, New South Wales S 31 16 04.3 E 149 05 58.6	16-115 GHz	22m dish, operated by CSIRO as part of the ATNF (Australia Telescope National Facility). Facility to be closed (temporarily remains open by crowd-funding).
Effelsberg Radio Telescope	Bad Münstereifel-Effelsberg near Bonn, Germany N 50 31 29.1 E 6 53 02.8	0.3-95.5 GHz	100m dish operated by Max Planck Institute for Radio Astronomy
Yebes RT40m (ARIESXXI)	Spanish National Obersvatory, Yebes, Guadalajara, Spain N 40 31 28.8 W 3 05 12.4	2.2-115 GHz	40 m parabolic steerable telescope for mm and cm wavelengths
IRAM - 30m	Pico Veleta Peak Sierra Nevada Andalusia, Spain N 37 03 58.2 W 3 23 33.8	80-300 GHz	30m dish operated by the Institute for Millimetric Radio Astronomy (Institut de radioastronomie millimétrique, IRAM); works in the millimeter range (1mm to 3mm) both with superheterodyne and bolometric detectors.
Onsala Space Observatory 20m telescope	Onsala, Kungsbacka, Sweden N 57 23 44.8 E 11 55 35.4	2.2-116 GHz	20m telescope, enclosed in a geodesic radome
Metsähovi Radio Observatory	Kylmälä, Kirkkonummi, Finland N 60 13 04.1 E 24 23 35.3	2-150 GHz	13.7 m dish, operates at 2 to 150 GHz, surface accuracy 0.1 mm (rms). Operated by Aalto University
Bordeaux Obervatory POM1 Telescope	Floirac, Gironde, France N 44 50 05.5 W 0 31 33.6	75-120 GHz	2.5m steerable paraboloid, for spectral line observations.
Plateau de Bure Interferometer	Plateau de Bure, Grenoble, France N 44 38 01.7 E 5 54 24.1	81-375 GHz	The interferometer consists of six antennas with a diameter of 15m each. These antennas can be placed in a T-shaped pattern, with North - South track of 368m and an East - West track of 768m. There are 32 stations along tracks where the antennas can be positioned.
Northern Extended Millimeter Array	Plateau de Bure, Grenoble, France N 44 38 01.7 E 5 54 24.1	70-375 GHz	Extension/expansion of the Plateau de Bure Interferometer to 12 antennas, with longer baselines and improved receiver performance.
Delingha 13.7 m	Delingha, Qinghai, China N 37 22 24.0 E 97 33 36.0	85-115 GHz	Dish diameter: 13.7 m. Site altitude: 3200 m. Operated by Purple Mountain Observatory.
Nobeyama 45m Radio Telescope	Nagano Prefecture, Japan N 35 56 40.2 E 138 28 20.7	20-150 GHz	A 45m single-dish short-millimetre telescope operated by the National Astronomical Observatory of Japan (NAOJ).
Nobeyama Millimeter Array	Nagano Prefecture, Japan N 35 56 34.7 E 138 28 15.8	80-230 GHz	Six 10m telescopes operated by the National Astronomical Observatory of Japan (NAOJ).
RT-7.5 (Bauman's Radio Telescope)	Orevo, Moscow Oblast, Russia N 56 25 54.0 E 37 27 57.0	75-300 GHz	Two 7.75-meter diameter antennas.
Galenki Radio Telescope	Primorsky Krai, Russia N 44 00 56.9 E 131 45 26.0	5-300 GHz	70m telescope, operating range 5-300 GHz
Yevpatoria Radio Telescope	Yevpatoria, Crimea N 45 11 20.6 E 33 11 13.8	5-300 GHz	70m telescope, operating range 5-300 GHz
Suffa Radio Telescope	Suffa Plateau, Uzbekistan N 39 37 25.9 E 68 26 51.4	5–300 GHz	70m telescope, operating range 5-300 GHz
Qitai Radio Telescope	Qitai County, Xinjiang, China N 43 36 04.0 E 89 40 57.0	300 MHz-117 GHz	Planned 110m telescope. Will be operated by XAO (Xinjiang Astronomical Observatory).

Name	Location	Frequency Range	Remarks
Taeduk Radio Astronomy Observatory	Daejeon, South Korea N 36 23 52.3 E 127 22 31.1	80-115 GHz	13.7m radio telescope for spectral line observations
ARO 12m Radio Telescope	Kitt Peak National Observatory, Papago, Arizona, USA N 31 57 12.0 W 111 36 53.5	83-116 GHz	Previously operated by the NRAO, this telescope is currently operated by the University of Arizona's Arizona Radio Observatory on Kitt Peak.
Combined Array for Research in Millimeter-wave Astronomy (CARMA)	Owens Valley Radio Observatory, Big Pine, California, USA N 37 16 43.0 W 118 08 32.0	27-270 GHz	Heterogeneous interferometer array composed of 6 10-m elements, 9 6-m elements, and 8 3.5-m elements covering frequencies ranging from 27–35 GHz, 85–116 GHz, and 215–270 GHz. Operated by partnership between Caltech, Berkeley, Illinois, Maryland, and Chicago with significant funding from the NSF.
Green Bank Telescope (GBT)	Green Bank, West Virginia, USA N 38 25 59.2 W 79 50 22.9	0.1-116 GHz	World's largest 100-metre (330 ft) fully steerable single-dish radio telescope
Haystack Observatory	Westford, Massachusetts, USA N 42 37 23.4 W 71 29 17.2	20-115 GHz	37m radome-enclosed radar/radiotelescope, recently upgraded for operation at 95 GHz.
Large Millimeter Telescope (LMT)	Sierra Negra, Puebla, Mexico N 18 59 09.0 W 97 18 53.0	75-350 GHz	The world's largest single-aperture telescope in its frequency range, built for observing radio waves in the wave lengths from approximately 0.85 to 4 mm. It has an active surface with a diameter of 50 metres (160 ft) and 1,960 square metres (21,100 sq ft) of collecting area.
Owens Valley VLBA Station	Owens Valley, Big Pine, California, USA N 37 13 54.0 W 118 16 37.2	1.2-96 GHz	One of the Very Long Baseline Array (VLBA) stations in the 10-station interferometer. Each VLBA station consists of a 25 m antenna and an adjacent control building.
Brewster VLBA Station	Brewster, Washington, USA N 48 07 52.4 W 119 41 00.0	1.2-96 GHz	One of the Very Long Baseline Array (VLBA) stations in the 10-station interferometer. Each VLBA station consists of a 25 m antenna and an adjacent control building.
North Liberty VLBA Station	North Liberty, Iowa, USA N 41 46 16.9 W 91 34 27.0	1.2-96 GHz	One of the Very Long Baseline Array (VLBA) stations in the 10-station interferometer. Each VLBA station consists of a 25 m antenna and an adjacent control building.
Hancock VLBA Station	Hancock, New Hampshire, USA N 42 56 01.1 W 71 59 11.9	1.2-96 GHz	One of the Very Long Baseline Array (VLBA) stations in the 10-station interferometer. Each VLBA station consists of a 25 m antenna and an adjacent control building.
Kitt Peak VLBA Station	Kitt Peak National Observatory, Papago, Arizona, USA N 31 57 22.7 W 111 36 45.1	1.2-96 GHz	One of the Very Long Baseline Array (VLBA) stations in the 10-station interferometer. Each VLBA station consists of a 25 m antenna and an adjacent control building.
Pie Town VLBA Station	Pie Town, New Mexico, USA N 34 18 03.7 W 108 07 09.3	1.2-96 GHz	One of the Very Long Baseline Array (VLBA) stations in the 10-station interferometer. Each VLBA station consists of a 25 m antenna and an adjacent control building.
Fort Davis VLBA Station	Fort Davis, Texas, USA N 30 38 05.8 W 103 56 41.5	1.2-96 GHz	One of the Very Long Baseline Array (VLBA) stations in the 10-station interferometer. Each VLBA station consists of a 25 m antenna and an adjacent control building.
Los Alamos VLBA Station	Los Alamos, New Mexico, USA N 35 46 30.5 W 106 14 44.4	1.2-96 GHz	One of the Very Long Baseline Array (VLBA) stations in the 10-station interferometer. Each VLBA station consists of a 25 m antenna and an adjacent control building.
Atacama Large Millimeter Array (ALMA)	Llano de Chajnantor Observatory, Atacama Desert, Chile S 23 01 24.8 W 67 45 14.3	31-950 GHz	54 dishes with 12m diameter and 12 dishes with 7m diameter, sensitive to wavelengths between radio and infrared (sub-millimeter astronomy).
Large Latin American Millimeter Array (LLAMA)	Alto Chorrillos, near San Antonio de los Cobres, Salta, Argentina S 24 11 31.4 W 66 28 29.4	35-720 GHz	12 m single dish, VLBI, in construction, expected to start operations in 2017
St Croix VLBA Station	St. Croix, Virgin Islands N 17 45 23.8 W 64 35 01.0	1.2-96 GHz	One of the Very Long Baseline Array (VLBA) stations in the 10-station interferometer. Each VLBA station consists of a 25 m antenna and an adjacent control building.
Mauna Kea VLBA Station	Mauna Kea Observatory, Hawaii, USA N 19 48 04.9 W 155 27 20.0	1.2-96 GHz	One of the Very Long Baseline Array (VLBA) stations in the 10-station interferometer. Each VLBA station consists of a 25 m antenna and an adjacent control building.

Per Table 2, the IPC for radio astronomy is: (a) -189 dBW, -129 dB(W/m^2), and -228 dB(W/(m^2 Hz)) for continuum observations; (b) -209 dBW, -148 dB(W/m^2), and -208 dB(W/(m^2 Hz)) for spectral line observations; and, (c) for VLBI observations, -172 dB(W/(m^2 Hz)). The assumed bandwidth for continuum and VLBI observation is 8 GHz and the bandwidth for spectral line observation is 1 MHz as discussed in ITU-R RA.769-2.

Per ITU-R RA.1513-2, the criteria for percentage of data loss is computed as the percentage of integration periods of 2000 s in which the interference levels at the radio telescope exceed the levels defined in Recommendation ITU-R RA.769-2.

We will analyze interference levels in terms of power per unit area (W/m^2) as seen at the radio astronomy antenna. As such, the IPC of -129 dB(W/m^2) and -148 dB(W/m^2) for continuum and spectral line observations are applicable. Assuming an 8 GHz observation bandwidth, the VLBI IPC of -172 dB(W/(m^2 Hz)) can be restated as -73 dB(W/m^2).

For the DVE Radar Sensor, the interference generated in a single pulse of the radar, expressed in power per unit area, is given by the equation:

$$I = \frac{P_t G_t(\theta, \varphi)}{(4\pi R^2) L_{atm}}$$

(Eq 3-1)

I is the interference level in W/m^2, P_t is the peak transmit power, $G_t(\theta, \varphi)$ is the gain of the radar antenna in elevation and azimuth, and R is the range from the radar system to the radio astronomy antenna. L_{atm} are atmospheric losses, approximately 0.4588 dB/km at 94 GHz per the atmospheric loss models given in ITU-R P.676-10, and using the "Mean annual global reference atmosphere" model as defined in ITU-R P.835-5.

The equation above represents the interference generated from one pulse. If we integrate the interference over one scan of the radar's field of view, and multiply by the percentage of time transmitting in that scan, we will get the average interference caused by the radar per unit time (in seconds):

$$I_{avg} = \left(\frac{T_x}{T_p}\right)\left(\frac{1}{T_f}\right)\sum_{FOV} \frac{P_t G_t(\theta, \varphi)}{(4\pi R^2) L_{atm}}$$

(Eq 3-2)

I_{avg} is the average interference level in W/m^2 for one second, T_x is the transmit pulse length, T_p is the interpulse period (inverse of the pulse repetition frequency of the radar), and T_f is the time to scan the field of view.

Based on the sensor parameters, the average interference generated by the radar out to a 200km range is shown in Figure 3 on the following page. As shown in Figure 7, interference from the main lobe of the scanning radar transmit pattern extends out to a range of almost 180 km. Interference perpendicular to the direction of flight extends out to approximately 60km.

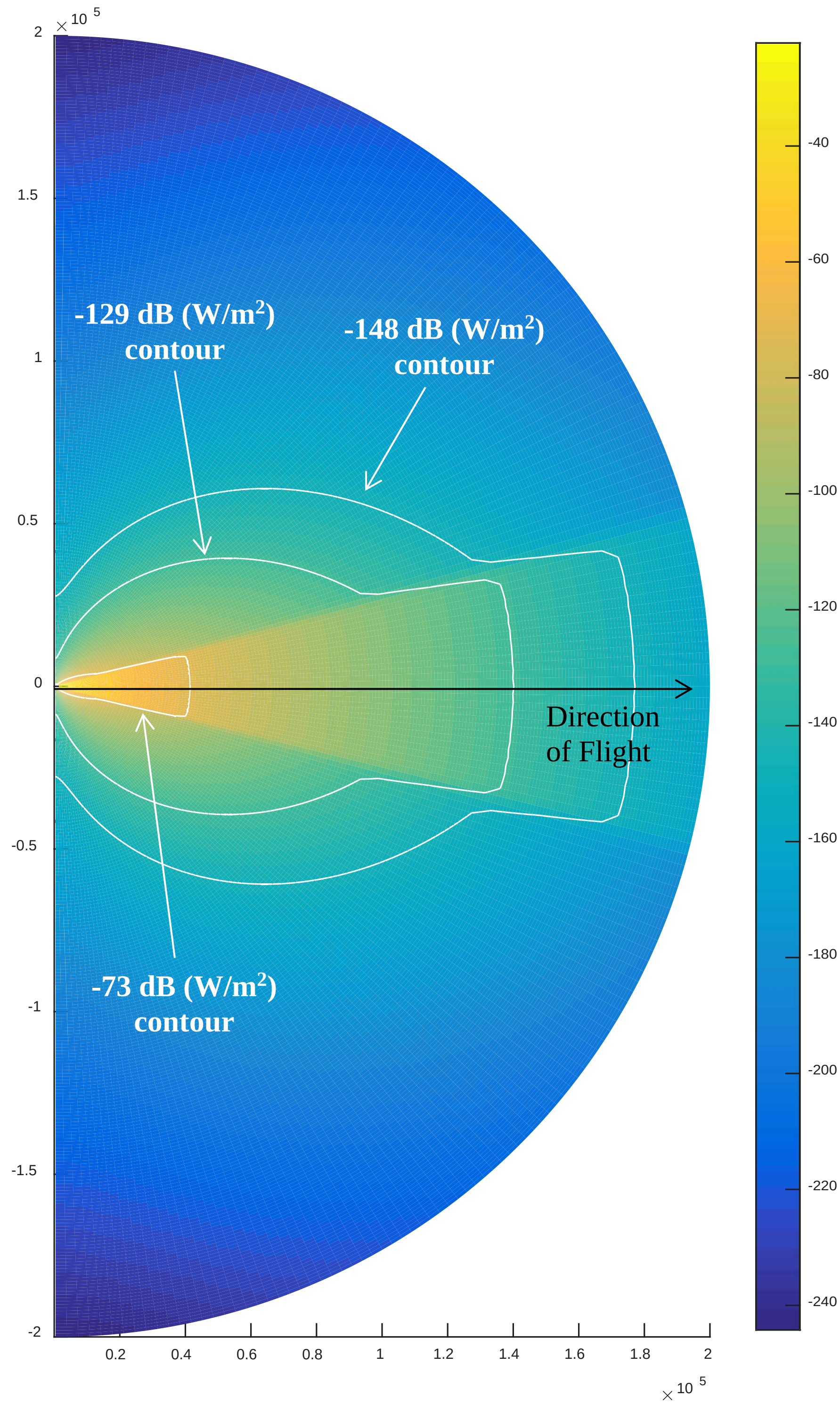

Figure 3. Average Interference Generated in dB (W/m^2) per second

To examine the probability of interference to the listed radio telescopes, we have adopted a Monte Carlo simulation analysis approach similar to the ITU recommended methodologies used in the analysis of mobile service interference.

The Monte Carlo simulation developed for this analysis examines use of SNC EFVS systems in aircraft landing and takeoff operations to/from airports and heliports within a 200km radius of the radio telescope sites listed in Table 3. Based on public information on 49,747 airports worldwide[2], and on statistical data of US airports from the FAA[3], the simulation models landing and takeoff operations from the nearby airports and heliports. The following factors taken into account:

- **Number of aircraft operations (landing or takeoff) –** Airports are classified as "large", "medium" or "small" in the public information data. Applying the FAA operations data for US airports, we computed an average of 431.4 operations per day at "large" airports, 124.8 per day at "medium" airports, and 34.8 per day at "small" airports. These averages were applied to other airports with unknown operations statistics (for non-US based airports).
- **Type of aircraft –** The simulation assumes four classes of aircraft—light, medium, heavy, and rotorcraft, with slightly different approach/takeoff speeds and climb/descent rates based on that aircraft class. The simulation also models a different mix of the different types of aircraft based on the airport size.
- **Landing/Takeoff Patterns –** The simulation includes the actual runway headings of the relevant airports, and models typical closed-traffic VFR and straight-in IFR approach headings.
- **Time of Day –** The simulation models varying aircraft operation levels based on the time of day, with heavier traffic between 6am and 10pm, and relatively light traffic overnight.
- **VFR/IFR Conditions –** Modeling for number of VFR vs. IFR operations was derived from annual weather data for the United States, obtained by internet search[4]. The model assumes 63% VFR and 37% IFR conditions on average based on this data.
- **Number of Systems In Use –** The simulation models an end-state where 2,500 fixed-wing systems (Model 0352) and 2,500 rotary-wing systems (Model 0452) have been delivered to the aviation marketplace.

  Fixed-wing systems are further distributed, with 10% installed in "light" aircraft, 40% in "medium" aircraft, and 50% in "heavy" aircraft. The model assumes 265,000 light aircraft, 100,000 medium aircraft, 50,000 heavy aircraft and 50,000 rotorcraft operating worldwide.

For each radio telescope site, the Monte Carlo simulation performs 315,360 iterations—the equivalent of 20 years of continuous operation by that radio telescope—in 2000 second integration time "chunks".

For each iteration, the simulation models aircraft operations probabilistically (taking the above factors into account), and computes the integrated interference level at each second of the 2000

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[2] OurAirports, Open data downloads, http://ourairports.com/data/, airports.csv and runways.csv files, accessed 31 Aug 2016.

[3] Federal Aviation Administration, Air Traffic Activity System (ATADS), http://aspm.faa.gov/opsnet/sys/Main.asp, custom report generated for calendar year 2015 with VFR/IFR operations, accessed 31 Aug 2016.

[4] Current Results, weather and science facts, "Total Cloudy and Foggy Days at US Cities a Year", https://www.currentresults.com/Weather/US/cloud-fog-city-annual.php, and "Average Annual Sunshine in American Cities", https://www.currentresults.com/Weather/US/average-annual-sunshine-by-city.php

second integration time from EFVS systems in use. Whenever the interference level is greater than -148 dB (W/m^2) at any point in the integration time, it is marked as "bad". If the interference level does not reach that IPC threshold, it is considered "good".

The simulation resulted in the following estimates for percentage data loss at each radio telescope site listed in Table 3:

Table 4. Estimated Data Loss Percentage for Radio Telescopes at 94 GHz

Name	Data Loss %	Name	Data Loss %
ARO 12m Radio Telescope	0.04%	Mauna Kea VLBA Station	0.02%
Atacama Large Millimeter Array (ALMA)	0.00%	Metsähovi Radio Observatory	2.05%
Australia Telescope Compact Array (ATCA)	0.51%	Mopra Radio Telescope	0.11%
Bordeaux Obervatory POM1 Telescope	1.48%	Nobeyama 45m Radio Telescope	0.14%
Brewster VLBA Station	0.42%	Nobeyama Millimeter Array	0.12%
Combined Array for Research in Millimeter-wave Astronomy (CARMA)	0.06%	North Liberty VLBA Station	0.38%
Delingha 13.7 m	0.00%	Northern Extended Millimeter Array	0.43%
Effelsberg Radio Telescope	3.15%	Onsala Space Observatory 20m telescope	3.48%
Fort Davis VLBA Station	0.02%	Owens Valley VLBA Station	0.10%
Galenki Radio Telescope	0.10%	Pie Town VLBA Station	0.01%
Green Bank Telescope (GBT)	0.34%	Plateau de Bure Interferometer	0.42%
Hancock VLBA Station	1.67%	Qitai Radio Telescope	0.00%
Haystack Observatory	3.76%	RT-7.5 (Bauman's Radio Telescope)	4.73%
IRAM - 30m	0.00%	St Croix VLBA Station	0.74%
Kitt Peak VLBA Station	0.04%	Suffa Radio Telescope	0.00%
Large Latin American Millimeter Array (LLAMA)	0.01%	Taeduk Radio Astronomy Observatory	1.63%
Large Millimeter Telescope (LMT)	0.00%	Yebes RT40m (ARIESXXI)	0.61%
Los Alamos VLBA Station	0.15%	Yevpatoria Radio Telescope	0.84%

Data loss due to interference at all of the relevant radio telescope sites is less than the 5% value recommended by ITU-R RA.1513-2.

More details of the Monte Carlo simulation model are provided in Appendix A.

4.0 SUMMARY

The purpose of this paper was to analyze interference levels generated by operation of SNC Enhanced Flight Vision Systems that include a 94 GHz terrain scanning radar sensor. The interference levels were compared to Interference Protection Criteria for the radio astronomy service operating in and around the 92.5 to 95.5 GHz operating bandwidth of the EFVS radar sensor.

In all cases, the EFVS radar was shown, by simulation, to meet IPCs for the radio astronomy service. As an aerospace company, SNC is supportive of radio astronomy science and looks forward to interaction with the radio astronomy service to limit interference with their important mission, while allowing us to share a frequency band and provide an important safety tool to the aviation community.

* * *

I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct to the best of my knowledge. Executed on the 26th day of September, 2019.

9/26/2019

X /s/ John Schneider

Signed by: John Schneider

John Schneider
Chief Engineering - Enhanced Vision Systems
Sierra Nevada Corporation

APPENDIX A - Details on Monte Carlo Simulation

This appendix provides further details on the Monte Carlo simulation and supporting data used in development of this analysis.

As discussed in the document body, the interference analysis is based on a Monte Carlo simulation of airport landing and takeoff operations near radio telescope sites identified as operating in the 92.5 to 95.5 GHz frequency bands.

Airport Data

Airport operations data was derived from two sources: (a) the Federal Aviation Administration Air Traffic Activity Data System (ATADS), which provided operations data for 517 airports for calendar year 2015 (see footnote 3); (b) a large, public-domain list of all airports worldwide (see footnote 2).

The public-domain list of airports downloaded from the "OurAirports" web site yielded a list of 49,747 airports worldwide. This list provides identification codes, coordinates, runway information, and classification (large airport, medium airport, small airport, seaplane base, and heliport) for all of the listed airports.

For airports on this list for which real operations data was available (from the FAA ATADS data), those operations statistics were used directly in the simulation. For those airports for which no data was available (either very small and/or private-use airports in the US, or international airports), operations data was estimated based on the ATADS data and the "large", "medium", and "small" airport classifications.

All airports were identified that were located within a 200km radius of each of the 36 radio telescope sites operating in the 92.5 to 95.5 GHz band (as listed in Table 3). Each of those airport sites was examined using Google Maps to verify location, runway headings, and relative size of the airport operation. In the course of location verification, additional airports that were closed/abandoned or too small (private use) were also pruned from the airport list.

Aircraft Types

Aircraft types were modeled/categorized as small, medium, and heavy aircraft, and rotorcraft (helicopters) in the simulation. For each type of airport, the relative numbers of the different types of aircraft operating at each airport size was modeled based on the operations data.

Aircraft Operations

The airport size/types were modeled as discussed above, with large airports averaging 431.4 operations per day, medium airports averaging 124.8 per day, and small airports 34.8 per day.

In the model, the nominal rates of aircraft operations are skewed based on an assumed time of day in the simulation. During daylight hours, operations occur at a higher rate, and overnight, the operation rate is reduced.

Table 5. Operations Per Hour Multiplication Factors

Multiplication Factor for Hour Beginning											
12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am
0.072	0.072	0.072	0.072	0.072	0.792	1.584	1.584	1.584	1.584	1.584	1.584

Multiplication Factor for Hour Beginning											
12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
1.584	1.584	1.584	1.584	1.584	1.200	0.960	0.960	0.720	0.720	0.600	0.264

So, for example, a large airport averaged 431.4 operations per day. This is equivalent to 0.005 operations per second. Depending on the time of day, this 0.005 operations per second rate was multiplied by a factor as given in Table 5. At noon, there would be (1.584 * 0.005) operations per second (equivalent to a landing or takeoff operation every 2 minutes). At midnight, there would be (0.072 * 0.005) operations per second (equivalent to about one an hour).

Aircraft landing and takeoff times are simulated using a Poisson point process with λ computed from the airport operations data, distributed per time of day by the factors in Table 5.

Weather

As noted in Section 3.1, the number of VFR vs. IFR operations was derived from US weather statistics (see footnote 4). The percentage of bad weather conditions in which one of our EFVS systems would be used is modeled as 37% of the time. These conditions are assumed to persist for the whole 2000 second radio telescope integration time modeled.

Runway In Use

The simulation models the runway in use as fixed for the 2000 second integration time of the radio telescope. As noted above, the available runway headings for each airport near the radio telescope sites were identified from Google Maps satellite imagery views and included with the airport data as input to the simulation. The simulation would randomly pick one of the available runways as the one “in use” for each integration time simulated.

Aircraft Takeoff Profile

All aircraft takeoffs are modeled as straight-out takeoffs. Takeoff and climb-out speeds (horizontal and vertical, respectively) were modeled as slightly different depending on aircraft type, varying from 120 knots for small aircraft to 160 knots for larger aircraft.

Aircraft IFR Landing Profile

Aircraft landings in IFR are modeled as a straight-in approach on a 3 degree glide slope. Approach speed varies from 120 knots for small aircraft to 160 knots for large aircraft.

Aircraft VFR Landing Profile

Aircraft landings in VFR are modeled using a normal left/right turn landing pattern around the airport. The aircraft uses a 1,000 foot above-ground-level (AGL) pattern altitude, with a 1 and ½ mile (3 kilometer) base leg offset, as shown in the figure below. Aircraft approach the aircraft at a random heading, intersecting with the left or right of the VFR pattern base. The aircraft descends to reach the 1,000 foot AGL pattern altitude at the base intersection. The aircraft maintains the 1,000 foot altitude along the base of the landing pattern, then turns to intersect the runway heading and begins its landing descent.

Note that it was not our intent to develop a highly accurate simulation of aircraft performance nor exercise a large variety of landing (or takeoff) scenarios. The intent of the simulation is to model the number of aircraft operating in the area of the radio astronomy site, model the predominate headings used by the aircraft in the runway traffic patterns, and add random airport approach angles/usage. In addition, the simulation adds a random -5° to +5° crab angle (with uniform distribution) and a with 3° standard deviation gaussian random distribution on top of the nominal aircraft headings. The result is a distribution of aircraft locations and headings that predominately follow the base/approach headings, but with sufficient randomness to exercise all headings with respect to the radio telescope.

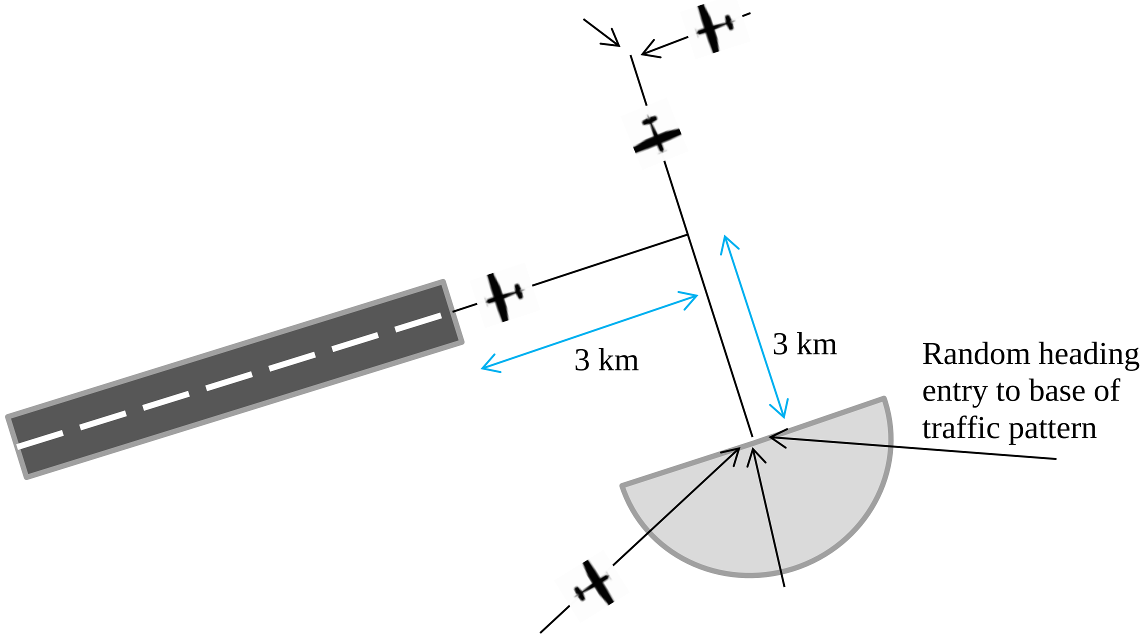

Figure 4. Aircraft VFR Landing Profile

Helicopter Takeoff Profile

All helicopter takeoffs are modeled as straight-out departures. Takeoff and climb-out speeds (horizontal and vertical, respectively) are modeled as 90 knots and 1000 ft/sec, respectively. Heading is chosen randomly (uniform distribution over 360 degrees).

Helicopter VFR/IFR Landing Profile

All helicopter landings are modeled as straight-in approaches. Approach begins at maximum altitude of sensor operation (2,500 feet), drops to an altitude of 2,000 feet AGL for 3km, then descends to touchdown over another 3km distance.

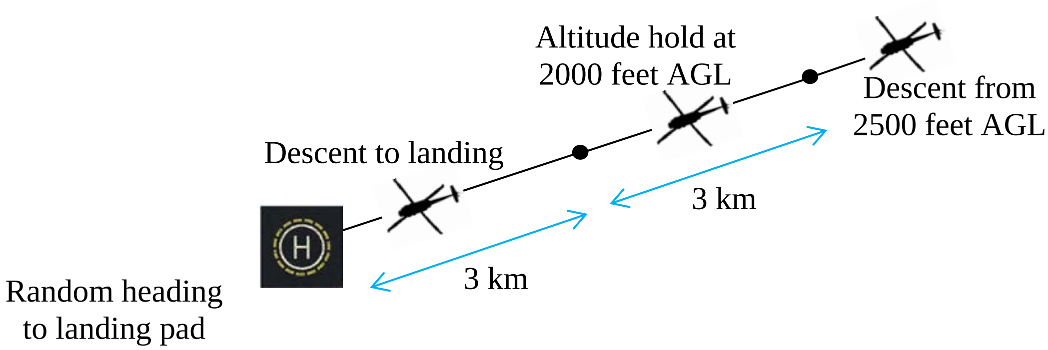

Figure 5. Helicopter Landing Approach

Number of Systems

A reliable source for the total number of aircraft in service worldwide was not found. We pieced together an estimate based on a number of sources, but the dates on which these estimates were published vary from 2005 to 2015, and there are questions concerning what aircraft are or are not included in any given estimate. The total compiled from these sources is:

362,000	Active General Aviation Aircraft[5]
20,300	Passenger Aircraft[6]
31,005	Military Aircraft[7,10]
20,410	Military Helicopters[8]
26,500	Civil Helicopters[9]

Other sources place the military aircraft & helicopter totals somewhat higher.

For our model, we assume 465,000 aircraft in service worldwide, with 50,000 helicopters and 415,000 fixed-wing aircraft (broken down further to 265,000 small/light aircraft, 100,000 medium aircraft and 50,000 heavy aircraft). We further assume that SNC will produce and have 5,000 EFVS units installed within the next 5 to 10 years, with 2,500 units installed in helicopters and 2,500 units installed in fixed-wing aircraft. (Note: SNC currently has none in production that are equipped with radar sensors.)

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[5] 2015 General Aviation Manufacturers Association (GAMA), 2015 General Aviation Statistical Databook & 2016 Industry Outlook, http://www.gama.aero/files/GAMA_2015_Databook_LoRes%20updated%203-29-2016.pdf
[6] USA Today, “Boeing: World’s airline fleet to double by 2033”, http://www.usatoday.com/story/todayinthesky/2013/06/12/boeing-predicts-commercial-aircraft-will-double-by-2033/2416131/
[7] GlobalFirePower, Total Aircraft Inventory Strength by Country, http://www.globalfirepower.com/aircraft-total.asp, accessed October 2016.
[8] GlobalFirePower, Total Helicopter Inventory Strength by Country, http://www.globalfirepower.com/aircraft-helicopters-total.asp, accessed October 2016.
[9] Helicopter Training Blog, “How Many Helicopters in the World?”, http://helicopterblog.com/?p=966

Thus, the probability of any one helicopter having one of our EFVS radar sensors installed is approximately 0.05% (2500/50000). The probability of any one fixed-wing aircraft having one of our sensors is approximately 0.006% (2500/415000).

System in Use

Even when installed in an aircraft, a pilot will not be using the system for every takeoff and landing. In good visibility conditions, the EFVS is not needed and should normally be turned off (as directed by procedure). The simulation models that the system will be used 100% of the time in bad weather/visual conditions, 0.1% of the time in the day in good conditions (testing and inadvertent use), and 1% of the time at night in good conditions (for additional situational awareness).

Radar Interference Levels and Line of Sight

The simulation models the radar interference levels as a function of relative heading with respect to the radio telescope are computed using (Eq 3-2) as depicted in Figure 3. This computation assumes a nominal atmospheric loss of 0.4588 dB/km and direct line-of-sight from the radar antenna to the radio telescope antenna.

The radar signal is considered occluded from the radio telescope when the radar is greater than 20 meters (65 feet) below any terrain at or above the telescope height. The telescope antenna height is assumed to be 60 meters (180 feet) above ground level. (See Figure 6.)

Terrain height is modeled using the SRTM30 digital terrain elevation model[10]. This terrain elevation model is based on the Shuttle Radar Topography Mission (flown in February 2000), supplemented by the USGS GTOPO30 terrain model (circa 1996). The model provides terrain elevation estimates at 30 arc-second spacing (approximately 1 km).

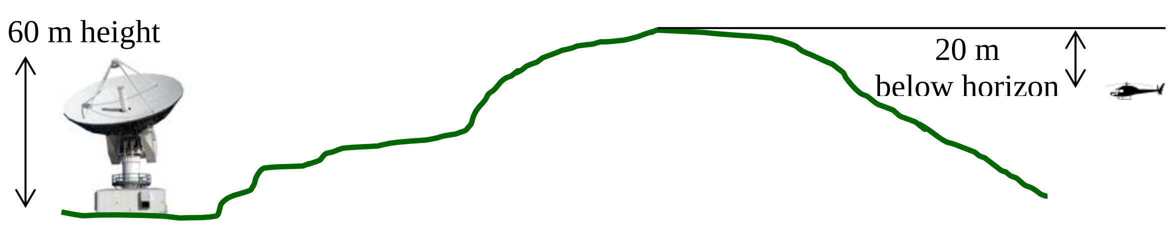

Figure 6. Radar Signal Occlusion

Exclusion Zone

The simulation allows an exclusion zone to be defined around the radio telescope site. A 30 kilometer exclusion zone (inside of which the EFVS radar system will not be permitted to operate) is defined for the analysis results provided herein.

[10] United States Geological Survey (USGS), SRTM30, https://dds.cr.usgs.gov/srtm/version2_1/SRTM30/srtm30_documentation.pdf